Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

SHOUT
SHARE
IT

8AD

UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1185

Washington, D. C. ▼ October, 1923

FLAX-STEM ANATOMY IN RELATION TO RETTING.

By ROBERT L. DAVIS, *Assistant Plant Breeder, Office of Fiber Investigations, Bureau of Plant Industry.*

CONTENTS.

	Page.
Introduction	1
The retting objective and some factors that may interfere	2
The progress of retting in the different tissues of the stem	5
Some macroscopic and external changes in the flax stem during retting	12
Mechanical methods of testing wet flax stems for completion of retting	16
Summary	26

INTRODUCTION.

The flax stem consists of two main parts, the central wooden core, lined with pith, and the cortex or bark, which completely encircles the wooden core. Between the wooden core and the bark lies the cambium layer, commonly known as the green inner bark. The fiber bundles are located in the cortex. The process of retting has the double object of separating the cortex from the wooden core and the fiber bundles from the nonfibrous portions of the cortex.

Numerous efforts to ret flax by chemical methods have thus far failed to be sufficiently successful to supersede the natural methods of dew retting and water retting. In dew retting the stems are spread out on a meadow for four to six weeks, and irregular weather conditions may result in a very uneven product. In water retting the flax stems are submerged in water, and retting is accomplished by the activity of bacteria, which dissolve the gums that hold the fibers to the surrounding tissues. Water retting may be controlled more satisfactorily than dew retting, is a more rapid process, and usually results in a more uniform product than dew retting. The scope of this bulletin is confined to water retting.

One of the chief difficulties experienced in water retting is that of deciding when to discontinue the process. If the stems are removed before the critical point is reached the fiber will not be well separated from the cortex and will be both coarse and harsh. If the process is carried beyond the critical point of complete retting the

55159—23——1

fibers will be seriously weakened through the dissolution of the pectin or gum that holds together the fiber cells forming the strands or commercial fibers.

Many practical retters assert that the only reliable test for the completion of retting is to remove several handfuls from different parts of the retting tank and examine the quality of the fiber after it is dried. Many retters depend upon the Belgian or loose-core test made on wet stems freshly removed from the retting tank; in this case retting is said to be complete when the wooden core may be pulled out from the fibrous cylinder without any resistance to the pull. The objection to the first or dry-straw method is that fiber may be injured by artificial drying unless proper humidity is maintained in the drying room. It is impracticable to have to wait for the sample to dry naturally in the sun on account of the danger of overretting with the remainder of the flax stems in the retting tank, and it is rather expensive to equip a drying room so as to maintain proper humidity. The second method, that of the loose-core test, is very undependable in inexperienced hands and not entirely dependable in the hands of experienced retters. A positive loose-core test indicating that retting is complete may at times be obtained when retting is far from complete and when the fibers are still firmly attached to the rest of the cortex. The study reported in this bulletin was undertaken to determine whether there existed a relation between the flax-stem anatomy and retting that would be helpful in testing wet flax stems for the completion of retting more accurately than can be done through the use of the loose-core test.

THE RETTING OBJECTIVE AND SOME FACTORS THAT MAY INTERFERE.

The object of retting is to obtain perfect fiber and to terminate the process so that the best balance of softness and strength of fiber results. Flax fiber, in general, is graded according to strength, fineness, weight, length, color, and freedom from shives, or pieces of the wooden core. The best quality of flax fiber is strong, very fine in diameter, soft, feels heavy to the hand, averages 20 inches or more in length, and is entirely free from shives. Light-cream and silvery-gray colors are common with good flax fiber, but the color is not so important as the other qualities. A silken luster is considered desirable, as this indicates that the fiber is well retted. If the flax stems are underretted the fiber is apt to be green in color, due to adherent chlorophyll from the cambium layer, and the fibers may not be separated from the rest of the cortex. Overretted flax fiber is generally dull gray, lacking in luster, and so very weak that it may be pulled to pieces by the hands with little effort.

After the retting process is completed the flax stems are dried and the mechanical separation of the wooden core from the retted fiber is performed by the breaking and scutching processes. In breaking, the flax stems are run through a series of corrugated rollers. This breaks up the wooden core into short pieces known as shives. Well-retted flax fiber is soft, strong, and pliable, so that it bends between the corrugations of the rollers without breaking

and comes through the machine uninjured. In scutching, the fiber, which has been run through the brake, is evened up and exposed to the blows of a paddle wheel which beat off any shives that remain clinging to the fiber. If the fiber is much overretted, it will be weak and go to pieces as it passes through the brake. If it is underretted, the shives will cling persistently to the fiber, and much long fiber will be wasted in the scutching process before the shives can be beaten off.

The factors that interfere with the retting objective may be divided into those of variable straw quality and those due to variable retting conditions. The freedom from shives, and the luster, the color, and the softness of the fiber are almost entirely determined by the management or mismanagement of the retting process, but nearly all the other characters on which flax fiber is graded may be influenced by the straw quality, which is, in turn, influenced by the manner in which the crop is cared for, as well as by the kind of seed used, the quality of the soil, and the season or climate.

STEM FACTORS AFFECTING RETTING.

Strength of fiber may be influenced by the variety of seed used or by the soil. Different varieties of fiber flax differ considerably in the strength of fiber. Stems of White Blossom Dutch have less fiber strength than stems of Blue Blossom Dutch of equal diameter, and the fiber in the stems of Saginaw, a variety selected for superior stem length and strength of fiber, has greater strength than that in either of the preceding varieties.[1] Flax stems produce weaker fiber when grown in marshy or sandy soils [2] than when grown in clay-loam soil. The strength of fiber may be influenced also by season or climate; a dry climate or season produces fiber that is relatively weak.

The fineness of fiber is influenced both by heredity, as represented by differences in the varieties of seed used, and by environment, as represented by the growing conditions. The fiber of White Blossom Dutch is coarser than that of Blue Blossom Dutch, due to hereditary differences.[3] According to hand-lens examinations of fiber from the 1922 crop at East Lansing, Mich., the fiber of White Blossom Dutch is coarser than that of Blue Blossom Dutch, even when stems of equal diameter are compared. The thickness of the stand of flax as controlled by the rate of seeding or by injuries from frost or disease determines the size and the uniformity of the stem diameter. A thick stand that has not been injured by frost or disease causes crowding of the flax plants and produces stems of fine diameter. Stems of fine diameter in turn produce fine fiber. Figure 1 shows at the left unretted fibers taken from a stem of Blue Blossom Dutch 1.3 millimeters in diameter. Compare the fine quality of this fiber with the relatively coarse fiber shown at the right from a stem

[1] Davis, Robert L. Pedigreed fiber flax. U. S. Dept. Agr. Bul. 1092, p. 18. 1922.

[2] Sellergren, Gustaf. Inhemska fiberväxter. *In* K. Landtbr. Akad. Handl. och Tidskr., arg. 60, p. 388–424, 13 fig. 1921. (Manuscript translation by Ebba Oleson Campbell, p. 10. On file in the Office of Fiber Investigations, Bureau of Plant Industry.)

[3] Tammes, Tine. Die blau-blümigen und weiss-blümigen Flachsarten und ihre Bedeutung. *In* Forsch.-Inst. Sorau Verbandes Deut. Leinen-Industrieller Mitt., Jahrg. 2, Nr. 6–7. 1920? (Manuscript translation by Lucile Reinbach, p. 9. On file in the Office of Fiber Investigations, Bureau of Plant Industry.)

of the same variety 1.7 millimeters in diameter. The photograph here reproduced represents the average size, enlarged six times, of fiber bundles that may be found in stems of these respective diameters and shows how close the association is between fine stems and fine fiber.

Measurements were made of the fiber bundles from stems of a selection in which the variations due to heredity have been eliminated and the variation in fiber size may be regarded as due almost entirely to the differences in stem diameter. The fiber bundles of this selection, Yale (10), a strain selected at Yale, Mich., in 1920, measured from 0.06 to 0.07 millimeter in stems 1.5 millimeters in diameter. The fiber bundles in stems 1.1 millimeters in diameter taken from the same selection were less than 0.04 millimeter in diameter. The term diameter in reference to fiber bundles means the width measured tangent to the circumference of the stem.

The average number of fiber bundles is not materially less in a stem of small diameter, and the fiber bundles are necessarily smaller in the fine stems, as they are crowded together into a smaller girth of cortex. Since the opposite is also true, a thin stand of flax results in stems of large diameter that produce coarse fiber. For best results the stems should be uniform and should not be more than 1.4 millimeters or much less than 1.2 millimeters in diameter. It is only when large and small stems that fall outside of this range are included that there is much variation in the number of fiber bundles due to the stem-diameter variation.

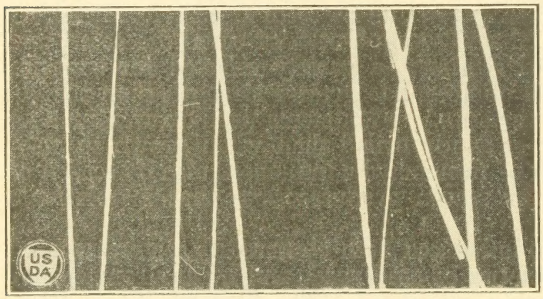

FIG. 1.—Variation in the size of fiber bundles of flax due to differences in the diameter of the stem. The fibers on the left were taken from a stem 1.3 millimeters in diameter, and the relatively coarse fibers on the right were taken from a stem 1.7 millimeters in diameter.

Part of the lack of uniformity in fiber fineness in Blue Blossom Dutch is probably due to the great variety of strains of flax that are present in this variety. Strains that vary in stem length and in fineness of fiber have been selected from this variety in Ireland [4] and in the United States.[5] The possibilities that are present along this line of selection for increased fiber fineness are indicated by a study of the fiber bundles in two closely related pure lines. The influence of heredity has given 36 fine fiber bundles to one pure line selected from Blue Blossom Dutch, while to stems of the same diameter of another pure line it has given only 24 relatively coarse fibers which are fully half as broad again as those of the former.

It is not easy to untangle all the interrelating factors of environment and heredity, but it has been shown that the quality of the

[4] Hunter, H. Improvement of the flax crop by propagation from selected plants. *In* Jour. Dept. Agr. and Tech. Instr, Ireland, v. 15, p. 245–246. 1915.
Stewart, John W. The Irish flax-growing industry and how it may be improved, p. 126–129. Coleraine, Ireland. [1922?.]

[5] Davis, Robert L. Op. cit., p. 19.

fiber may be influenced indirectly by frost resistance. The coarse fiber produced by White Blossom Dutch is in part due to its marked susceptibility to frost, as its stand may be depleted by frost and coarse stems developed when varieties such as Blue Blossom Dutch and Saginaw escape with little injury.[6]

It has been shown that straw quality may influence the retting product in strength and fineness of fiber and that the hereditary quality of the seed as well as the soil, climate, and season all share in exerting this influence. Therefore the objective of retting, that of producing fiber of the best quality, can not be attained unless pains be taken to assure uniform straw quality. It is important that the stems be fine and of uniform diameter. If possible a strain of flax selected for strength and fineness of fiber should be used, so as to eliminate the variation that may occur even in stems of the same diameter. These precautions will eliminate most of the variables that affect retting and are due to straw quality, so that the variations that arise may be controlled through management of the retting process.

FACTORS OF THE RETTING PROCESS AFFECTING THE QUALITY OF THE FIBER.

The variables in the retting process itself are the nature of the retting bacteria, the temperature of the water, the rate of water circulation, the water quality (whether hard or soft), and the duration of the ret. Of these factors the one that causes most trouble is the duration of the ret, or making the decision as to when retting is completed. A study of the process of disintegration of the flax stem as retting proceeded was undertaken in order to find out what changes in the flax stems were closely associated with the completion of retting.

THE PROGRESS OF RETTING IN THE DIFFERENT TISSUES OF THE STEM.

The rapidity and order with which the different tissues in the flax stem are retted depends on the digestibility or solubility of the cementing substances that bind the tissues together, their accessibility, and the relative amounts of them present in the different tissues. The tissues of the flax stem that lie in the cortex may be divided into the fiber bundles, the phloem parenchyma lying between the fiber bundles and the cambium layer, the parenchyma lying between the fiber bundles themselves, the epidermis that incloses the stem, and the outer parenchyma that lies between the epidermis and the fiber bundles. (Fig. 2.)

Retting takes place first in the cambium layer (tissue 1, in fig. 2) where the pectin is quite soluble and where because of the very thin cell walls the layers of pectin or cementing substance are correspondingly thin. When flax stems are sterilized in water at 115° C. much of the pectin in the cambium layer is dissolved, and the cortex is so well loosened from the wooden core that the loose-core test is of no value at all as a positive indicator that retting is completed. The pectin in the tissues of the cortex is less soluble than that in the

[6] Davis, Robert L. Frost resistance in flax. U. S. Dept. Agr., Dept. Circ. 264, 8 p., 5 fig. 1923.

cambium layer and is not much affected by the solvent action of the hot water. It is not entirely because of a difference in accessibility that the cortex is retted after the cambium layer, as at the exposed surfaces of cut stems where all tissues are equally exposed to the attack of the bacteria, retting is not materially hastened in the cortex.

It is true, however, that the cambium layer, located on the inside of the stem, is somewhat more accessible to the attack of the bacteria than the tissues lying to the outside in the cortex. The stems

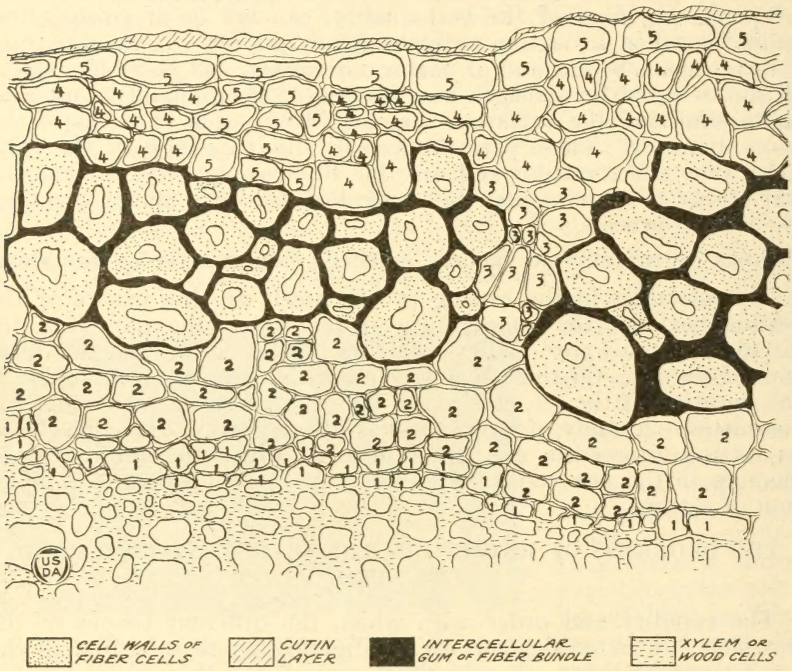

FIG. 2.—Cross section of flax stems, showing the consecutive order of the retting processes. The numbers indicate the order in which the tissue is destroyed by the bacteria. 1, The cambium layer; the cortex becomes loosened from the central wooden core. 2, The phloem parenchyma is disintegrated, exposing the insides of the bundles to the bacteria. 3, The parenchyma between the bundles is destroyed, separating the edges of the bundles and exposing the outer parenchyma to contact with the retting liquid. 4, Most of the outer parenchyma goes next, leaving the fiber bundles held together by the thick-walled epidermis. 5, The epidermis and the remainder of the outer parenchyma and the fiber bundles are now isolated. Note that the thickness of the intercellular gum between the fiber cells is greater than that of the cell walls in the adjacent parenchyma. (Camera-lucida drawing, enlarged 480 times.)

are partially protected from the outside by the waterproof nature of the cutin in the outer wall of the epidermis. The areas where the leaves drop off are waterproofed by the formation of leaf scars where suberin is deposited. At harvest time the waterproof covering on the outside of the stem is complete with the exception of the stomatal openings. Part of the stomata, as microscopic examination shows, are closed and made water-tight by the formation of cork cambium. The retting liquid and bacteria, however, can find their way through the epidermis, as the flax stems which have been paraffined at both ends will ret. The closing up of the ends, however, does

distinctly retard retting, indicating that the bacteria enter less readily through the epidermis than at the stem ends. These conclusions were drawn from the following experiment:

DETERMINING THE MODE OF ENTRANCE OF BACTERIA INTO THE RETTING FLAX STEM.

This experiment was made with the advice and assistance of R. A. Tweed and Miss Antoinette Trevithick in the department of bacteriology, Michigan Agricultural College, East Lansing, Mich.

Two sets of test tubes containing both sterilized and unsterilized straw were set up in series of six. Both the tops and the bottoms of the straw in three of each set were paraffined, while the other three were unparaffined. One set of six was inocculated and incubated under anaerobic conditions and the other under aerobic conditions for nine days at 30° C. After this period the straw was examined, and it was found that the fiber was weak and overretted in the case of the unparaffined in both aerobic and anaerobic sets. The paraffined sets showed the fiber to be strong and well retted under both aerobic and anaerobic conditions. These results were similar with both sterilized and unsterilized straw.

This experiment was run on four different occasions, the only difference being that unsterilized straw, as well as sterilized straw, and an aerobic culture were used in the first experiment while sterilized straw only and a facultative anaerobic culture were used in the other three experiments.

The results just described would indicate that the paraffined ends obstructed the entrance of the bacteria and retarded retting. As the culture used in three of the experiments consisted of a facultative organism, the results would further indicate that the retardation in retting was due to obstruction of the entrance to bacteria rather than the obstruction of the entrance to air. Inasmuch as the unparaffined sets retted more rapidly than the paraffined sets, it would indicate that the bacteria found more ready means of access through the ends of the stem than through the epidermis.

As the flax stems are but loosely filled with pith and are nearly hollow it is reasonable to assume that they contain a large quantity of air relative to the quantity present in the retting water in the test tubes. This would tend to disprove that the restriction in the air circulation was responsible for the retardation in retting.

The bacteria enter the flax stems through the broken ends of the roots; the inside of the flax stem is but loosely filled with pith cells at the center and is nearly hollow, so that once inside the root ends, the retting liquid containing the bacteria can find ready access through the entire length of the stem. The bacteria can then pass out into the cambium layer along the medullary rays between the sectors of wood or xylem. The cambium layer is thus most accessible to the attack of the bacteria, because it lies nearest the pith of the stem where bacteria find their way unobstructed and the almost complete waterproof covering on the outside of the stem forces the bacteria to first attack the stem from the inside and adjacent to the cambium layer. The cambium layer forms an unbroken cone running the full length of the stem excepting at the nodes, where the leaf scars interrupt its continuity.

The area that is next disintegrated by the bacteria is that occupied by the phloem parenchyma, which lies between the fiber bundles and cambium layer (tissue 2, in fig. 2). The inside surfaces of fiber bundles, when well retted, are nearly always more lustrous than the outside surfaces, indicating that the inside surfaces, lying

next to the phloem parenchyma, have been subjected to the action of the bacteria for a longer time and that the traces of the phloem parenchyma have been more completely destroyed than those of the outer parenchyma that lies next to the outside of the fiber bundles. The phloem parenchyma is more accessible than the outer parenchyma, since the former lies next to the cambium layer and the bacteria soon assimilate the small quantity of food material in the cambium layer. It does not take so long to destroy the phloem parenchyma as the outer parenchyma, because of the thinner layers of pectin present in the phloem parenchyma.

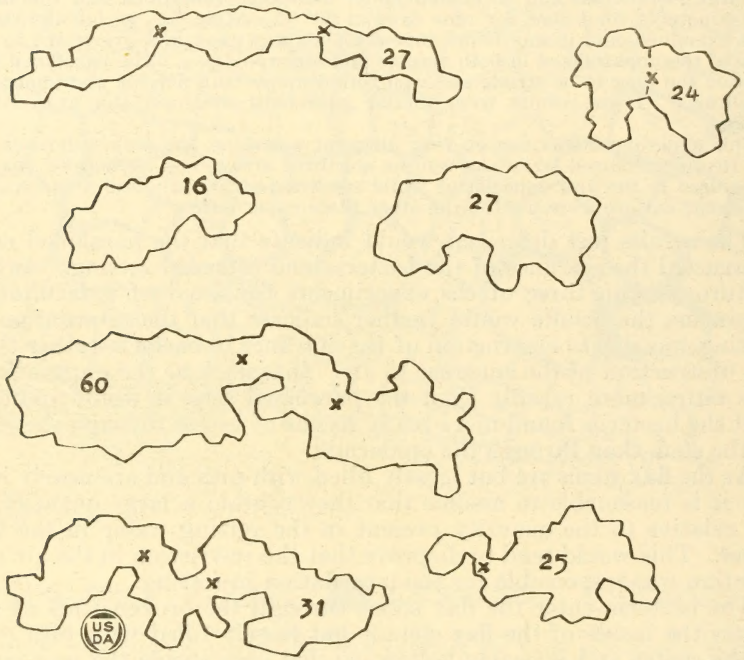

FIG. 3.—Fiber bundles of flax taken from the same stem, showing variations in the size, the shape, and the number of cells. The figures show the number of cells counted in each bundle. The outside edges of the bundles are uppermost. The crosses at the points of grooves indicate where separations would occur during retting. (Outline camera-lucida drawing, enlarged 140 times.)

After the phloem parenchyma is disintegrated the bacteria and the enzym pectase which they secrete are found next to the inside surfaces of the fiber bundles and the parenchyma that lies between them. The fiber bundles and the strips of parenchyma between them may be likened to a picket fence in which the "pickets" or fiber bundles are about five times as wide as the spaces. The comparison holds good from the standpoint of bacterial activity; the fiber bundles form obstructions to the progress of the bacteria both because the quantity of pectin present in the fiber bundles is many times as great as that in the areas between them and because the cementing substances between the fiber cells are partly woody and more or less impervious to the attacks of bacteria.[7] Examina-

[7] Tadokoro, T. Studies on flax retting. *In* Jour. Col. Agr. Tohoku Imp. Univ., v. 5, p. 34. 1913.

tions with the microscope of cross sections made at the end of this stage in retting show that the fiber bundles, outer parenchyma, and epidermis are intact and that the parenchyma between the fiber bundles has been destroyed.

The relation of the thickness of the pectin layer to the retting period is indicated by the shorter retting period of small stems. Stems 1.5 to 2 millimeters in diameter take 12 to 36 hours longer to ret than stems varying from 1 to 1.5 millimeters in diameter. The larger stems have thicker layers of pectin. The panicle end, which is the small end of the stem, rets before the root end of the stem, where the pectin layer is relatively thick.

As soon as the parenchyma between the fiber bundles is destroyed the retting liquid and bacteria surround the bundles on all sides excepting the outer surfaces that lie next to the outer parenchyma. According to Tadokoro the cell walls of the epidermis, excepting the cuticle, and the cell walls of the parenchyma and the middle lamellæ of the fiber cells are composed almost entirely of pectin compounds. Hence the relative thickness[8] of the walls of these tissues as compared with each other and with the middle lamellæ of the fiber cells give some idea as to the time it should take to break down these tissues in the retting process. A study of Figure 2 shows that the pectin layer is thickest in the fiber bundles, followed in order by the epidermis and outer parenchyma. The phloem parenchyma and that lying between the fiber bundles have pectin layers of about equal thickness but somewhat thinner than that of the outer parenchyma. Of all the tissues the cambium has the thinnest layer of pectin.

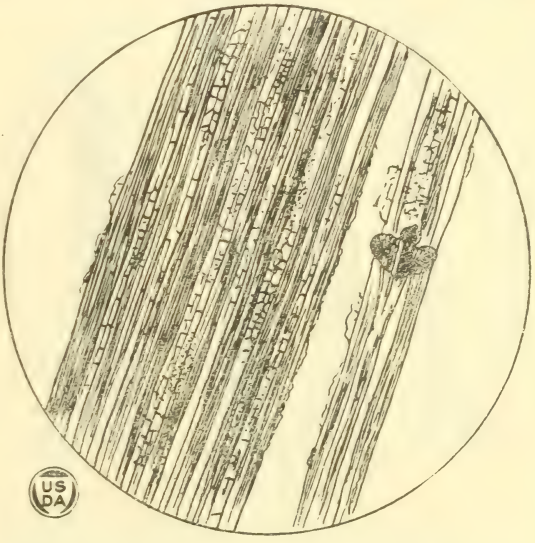

FIG. 4.—Changes in the appearance of the cortex of flax during the last stages of retting. The cortex is here shown separated from the wooden core, but still almost intact. × 10.

Since the layer of pectin in the cell walls of the epidermis is thicker than that in the outer parenchyma it would naturally be expected that the epidermis would not be destroyed until after the outer parenchyma. The path of bacterial activity is directed against the outer parenchyma, and microscopic examination shows that those portions of the outer parenchyma lying next to the spaces between the bundles are destroyed next (tissue 4, in fig. 2), leaving only the strips of outer parenchyma that are found in the middle of the outer surfaces of the bundles intact. The reason for this is that the bac-

[8] Tadokoro, T. Op. cit., p. 37.

teria have to work four or five times as far to meet at the middle of the outer surface of a bundle as to reach the epidermis.

The retting fluid now incloses almost nine-tenths of the circumferences of the fiber bundles, and the fiber bundles are held together only by the epidermis and the small strips of outer parenchyma lying at the middle of the outer surfaces of the bundles and bridging the space between the fiber bundles and epidermis. The retting of these two nonfibrous elements of the cortex that remain appears to occur almost at the same time as the separation of the fiber bundles into several smaller units that are known as commercial fibers, and when this last step is accomplished retting is completed. It is well known by flax retters that the disintegration of the epidermis occurs as about the last change in the retting process, and Tadokoro states that the cuticle is detached mechanically during the last stage of retting.[9] Whether these changes occur simultaneously depends somewhat upon the stem diameter; in very coarse stems the fiber bundles are not separated into smaller units until some time after the loss of the epidermis, owing probably to the extreme thickness of the pectin layers in the bundles.

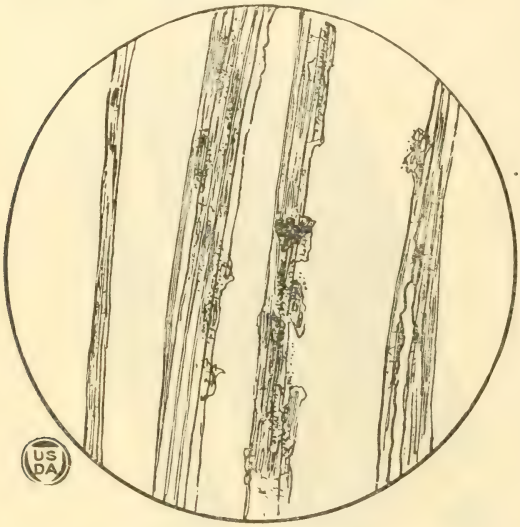

FIG. 5.—Changes in the appearance of the cortex of flax during the last stages of retting. The cortex is here shown separated into a number of smaller strips. Fairly large pieces of parenchyma and epidermis are clinging to the fiber bundles. × 10.

The fiber bundles are composed of several thousand fiber cells, and a cross section of one bundle will average about 25 cells in number. The fiber bundles vary in size and shape and in the number of cells. Figure 3 shows camera-lucida drawings of the outlines of fiber bundles taken from the cross section made at the center of a single flax stem. Some of the bundles are three or four times as large as others. Some have 60 cells, some have only 25, and some in extreme cases only 8 or 10 cells. Flax fiber bundles are not, as is commonly supposed, cylindrical or elliptical in cross section. On the contrary, they are irregular, being two or three to eight times as broad, measured parallel to tangents drawn on the circumference of the stem, as the thickness of the bundles measured radially. They are somewhat rounding to slightly zigzag in outline on the outer

[9] Tadokoro, T. Op. cit., p. 37.

surfaces and concave and grooved on the surfaces that face toward the center of the stem. From the standpoint of retting the degree of concavity is of interest, as the deep grooves furnish natural places for the separation of the fiber bundles during the retting process as well as during the subsequent processes of breaking and scutching. Frequently there is anastomosis of several fiber bundles coming up from the base of the stem, so as to form one large bundle, and it is quite common to find deep indentations marking the spots where union took place. These grooves make it easier for the large bundles to be retted and separated into smaller units. The irregular shapes and sizes of the fiber bundles help to explain the difficulty of obtaining a uniform ret and also explain why linen threads and cloth do not have the same uniformity as cotton of the same quality, since all cotton fibers are single cells of uniform diameter.

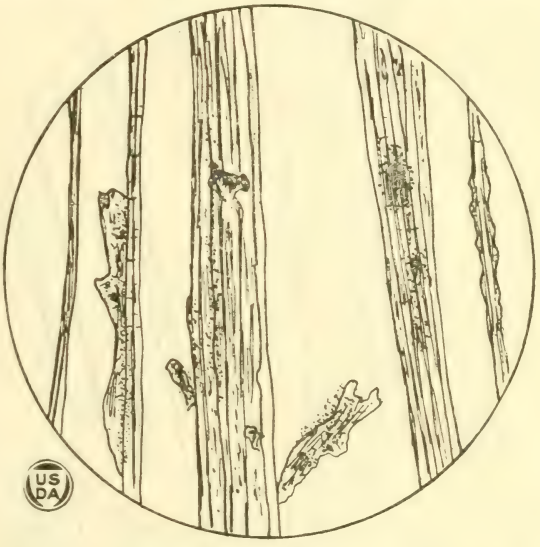

FIG. 6.—Changes in the appearance of the cortex of flax during the last stages of retting. Only a few pieces of epidermis and parenchyma here remain clinging to the fiber bundles, which are not yet separated into the small widths necessary for industrial use in spinning. × 10.

Figures 4 to 8, inclusive, show a series of external longitudinal views of the cortex and fiber during the last stages in retting. In Figure 4 retting has separated the cortex from the wooden core, but the cortex is still almost intact and undivided. The leaf scars have become translucent and show the bundle traces. In Figure 5 the cortex has separated into a number of smaller strips, the bacteria have destroyed most of the parenchyma and epidermis that held the fiber bundles together, but the epidermis and parenchyma are still clinging to the bundles in fairly large pieces. In Figure 6 only very small pieces of epidermis and parenchyma are found clinging to the fiber bundles, but the leaf scars persist, and the fiber bundles are not yet separated into the small widths of fiber necessary for industrial use in spinning. In Figure 7 retting is completed, the leaf scars have disappeared, the fiber bundles are entirely free from impurities, and are split lengthwise into fibers of suitable widths. The fibers in Figure 7 may be compared with those in Figure 8, in which a representative sample of uncombed water-retted Dutch fiber is shown.

The microscopical study carried along with the retting process confirms the work of other students of retting in that the outside of

the stem is the last to be retted. Very close to the time when retting is complete the fiber bundles separate into several smaller units, and the cuticle is detached from the outside of the stem. This study also points out that retting proceeds from the cambium layer toward the outside of the stem and that the waterproof union of the fiber bundles and wood branches formed by the leaf scars at the nodes, make retting at the nodes more difficult than in the internodes. These conclusions indicated that the search for a completion-of-retting test should be focused on the outside surface of the stem rather than on the area between the wooden core and the cortex occupied by the green inner bark or cambium layer.

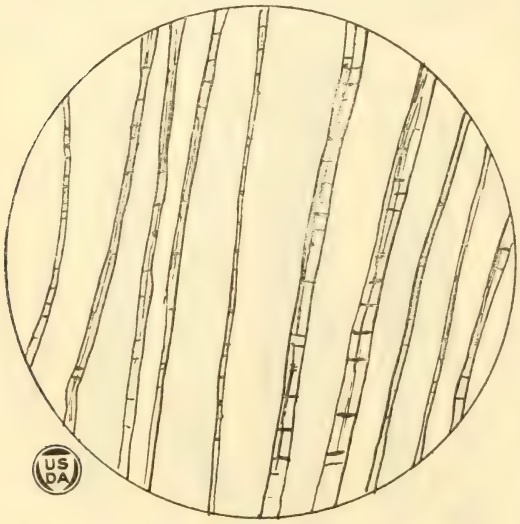

FIG. 7.—Changes in the appearance of the cortex of flax during the last stages of retting. The fiber bundles here shown are entirely free from impurities and are split lengthwise into fibers of suitable width, indicating the completion of the retting process. × 10.

SOME MACROSCOPIC AND EXTERNAL CHANGES IN THE FLAX STEM DURING RETTING.

Some retters claim that sliminess of the stem is closely associated with the end point of retting, and others claim that stem brittleness is thus associated.[10] In order to eliminate any chance of missing a change that is at all associated with the end point of retting, a list was made of the changes mentioned in the literature and those that have been noted in this study. The approximate sequence of these changes was determined by studying the retting process repeatedly. Observations were made every six hours and records were taken of the time when each change was first noted. Such changes as sinking of the straw, brittleness of stem, and maximum sliminess of stem are of little value, as they take place too far in advance of the completion of retting. Brittleness of the stem merely indicates that retting is proceeding satisfactorily and that stagnation has not occurred.

The loosening of the cortex from the wooden core, as determined by the Belgian or loose-core test, also occurs at times several days before the completion of retting in a 14-day retting period. Toward the end of retting the stems became gradually lighter in color (fig. 9), changing from a yellow-brown to a very light yellow or almost

[10] Huntley, F. A. Fiber flax investigations. Wash. Agr. Exp. Sta. Bul. 33, p. 18. 1898.

white color. This change in color is not dependable, as flax stems that are well cured may be practically white in color when first placed in the retting tank. The change in color is closely associated with the last stages in retting, although the eye may not be depended on to decide between the different degrees of lightness in color. This change may be noted as a color change or as a disintegration process in the exterior portion of the cortex. Figure 9 shows a gradual increase in lightness of color as the bacteria disintegrate the epidermis and the outer parenchyma. The stem on the left is distinctly cloudy and murky in color, owing to the loosened cell contents in the tissue between the cuticle and the fiber bundles, although the normal color of the unretted stem is light yellow-brown. In the center is shown a stem that is murky only in spots; the stem is light colored, and the cuticle is loosened excepting at these spots. On the right a stem is shown that is much lighter in color and whose retting is very nearly completed; the cloudy areas are very small, and the tissue between cuticle and fiber bundles appears to have been destroyed excepting in those areas. The maximum lightness in stem color is reached when the cuticle sloughs off. If the fibers are sufficiently washed at this point the naked fibers may be seen, glistening and transparent against the white background of the wooden core.

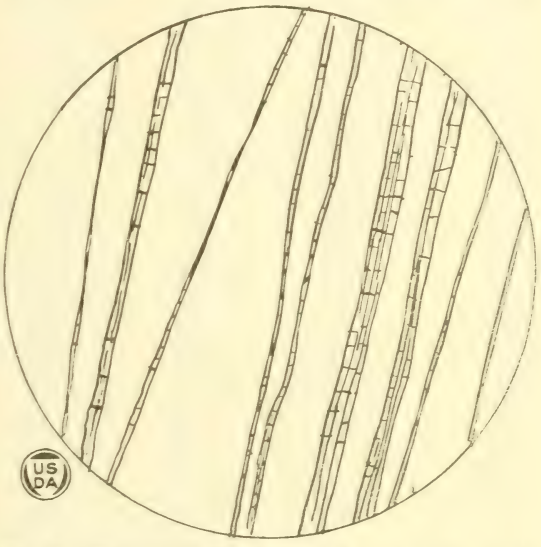

FIG. 8.—Water-retted Dutch fiber of good quality. Note the fineness of the strands and compare with those in Figure 7. × 10.

The leaf scars resisted the retting process of disintegration for a long time, and their disappearance was one of the last changes in the external appearance of the stem. Fiber bundles and the wooden core branch out into each leaf in the growing plant. When the leaves drop off at maturity the scars left by them are covered by a waterproof substance known as suberin that cements together the tip ends of the branches of the wooden core and fiber bundles that formerly fed each leaf. These areas are known as leaf scars and show up as dark-brown heart-shaped spots about 0.5 to 1 millimeter in diameter at intervals about every half inch or nearly every centimeter along the stem. This means that in a stem 75 centimeters (30 inches) long there will be close to 100 leaf scars forming waterproof unions between the fiber bundles and the wooden core. The

leaf scars also overlap the adjoining epidermis at each node, so that the waterproof union includes epidermis, fiber bundles, and wooden core.

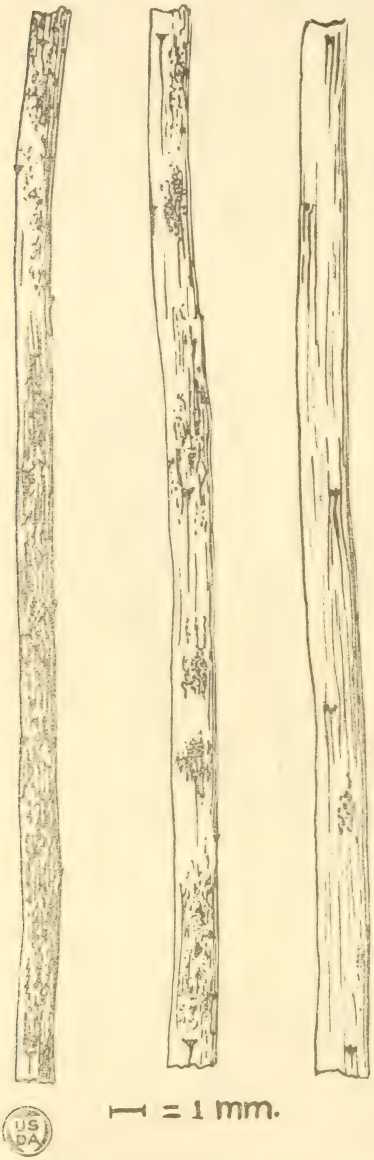

FIG. 9.—Changes in the color of flax stems during the process of retting. A gradual increase in the lightness of the stem color is to be noted during the last stages of retting. The light-colored stem on the right is almost retted.

The leaf scars cling persistently until toward the very last stage in retting. Figure 10 shows on the left a piece of unretted cortex spread out flat; note the distribution of leaf scars, represented by small black, triangular to heart-shaped spots. In the center the partly retted portion of a flax stem shows how, after breaking, the shives cling to the cortex at the nodes where the leaf scars occur. On the right is shown a piece of cortex that is almost through retting; note that the broad or coarse places in the fiber center about the leaf scars. Examinations were made of samples of good to medium grade fiber from Belgium, Holland, Japan, Chile, Ireland, and Canada. In the best grades of fiber which had been well retted no leaf scars could be found. In the underretted and coarse grades of fiber leaf scars were found where there were coarse places in the fiber.

Figures 11, 12, and 13 give some idea as to the nature and the persistence of the leaf scars. Figure 11 shows a piece of unretted cortex enlarged ten times. The fiber bundles show only as very dark strips. The structure of the epidermis is obscured by the tissues underlying it. The bundle traces are not visible in the leaf scar. An undeveloped bud is shown in the axil above the leaf scar. In Figure 12 retting has proceeded far enough to separate the wooden core from the cortex, but the cortex is almost intact. The cellular structure of the epidermis shows, as part of the underlying tissue has been destroyed. The leaf scar has been partly dissected away from the rest of the cortex. Note how persistently the branches of the fiber bundles cling to the leaf scar. Figure 13 shows a leaf scar and the surrounding tissue as it appears when retting is almost complete. The retting has removed nearly all the pa-

renchyma, and very little other than the fiber bundles and the epidermis remains. The tissue near the leaf scar has been destroyed and the leaf scar partly disintegrated, exposing the bundle traces.

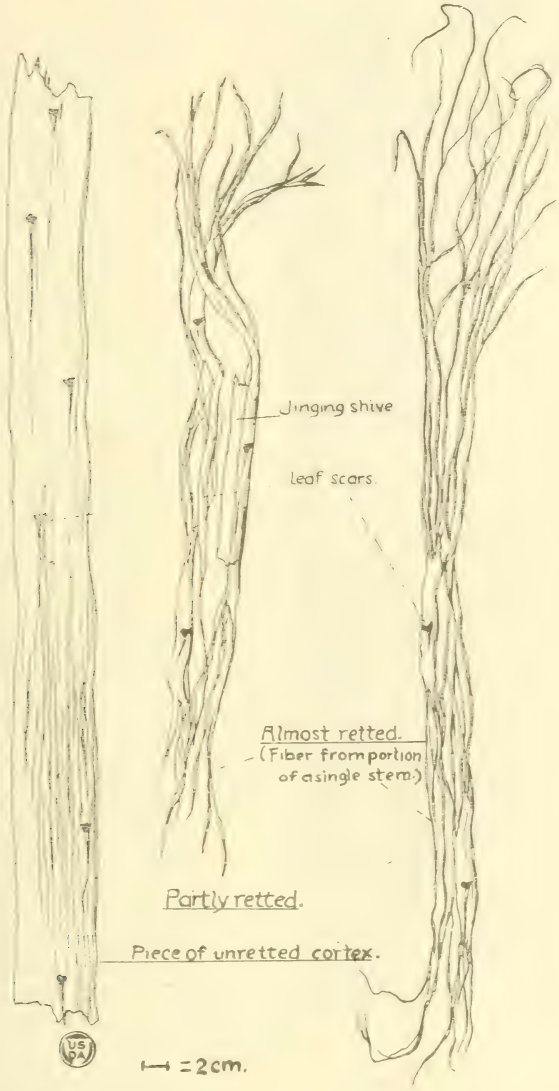

FIG. 10.—Leaf scars in retting flax. On the left a section of unretted flax cortex is spread out flat to show the distribution of the leaf scars. In the center is shown a piece of a partly retted flax stem and on the right a piece of almost retted cortex. Note that the broad places in the fiber center about the leaf scar.

The study so far indicates that no dependence can be placed upon the time of sinking of the straw or the external appearance of the stem as to color or sliminess and that all but three changes that

may be of use in testing wet stems may be eliminated. These changes are (1) the fineness of the fiber, which includes the completeness with which the cortex is separated into the fiber bundles and also the final separation of the fiber bundles, particularly the larger ones into several smaller units; (2) the disintegration of the epidermis, which includes the digestion of the pectin in the inner cell walls and the mechanical separation of the cuticle; and (3) the disappearance of the leaf scars as an indication that the waterproof unions of fiber and wood branches at the nodes are broken down.

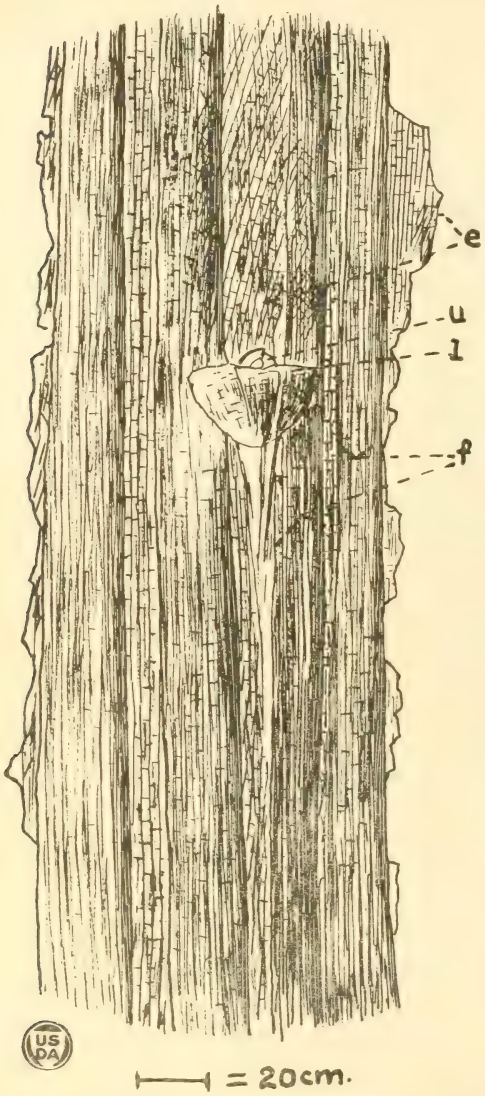

FIG. 11.—A piece of unretted flax cortex flattened out to show the exterior view. The structure of the epidermis (*e*) is obscured by the underlying tissue. The bundle traces are not visible in the leaf scar (*l*). The fiber bundles (*f*) show as dark strips. *u*=Undeveloped bud.

MECHANICAL METHODS OF TESTING WET FLAX STEMS FOR COMPLETION OF RETTING.

The problem that arose at this point in the study was how to devise a test or combination of tests for completion of retting that would include two or if possible all three of the changes most closely associated with completion of retting, namely, the disappearance of the leaf scars, the fineness of fiber separation, and the disintegration of the epidermis. The various steps in the Belgian or loose-core test were analyzed in order to determine why it is undependable and whether any part of it might be of use. In making the loose-core test the stem is broken about one-fourth of its length above the base end and the short piece discarded. The cortex or cone of retted fiber is then pushed back several centimeters from the broken end (fig. 14), so as to expose

the wooden core entirely free from any fibers. The wooden core is then broken 6 to 9 inches above the first break (fig. 15), the worker being careful not to leave any jagged pieces of wood that would catch on the fibers when the test is made. In the third step one hand grasps the stem above the second break and the other pulls on the exposed lower end of the wooden core (fig. 16). In a positive loose-core test (fig. 17) the wooden core slips out from the cortex without any clinging on the part of the fibers. The cortex or fibrous cone pulls away from the wooden core as a single unit, and therefore the loose-core test does not give any idea as to the fineness of division of the fibers. For the same reason it does not give any indication as to the degree of disintegration of the epidermis, for even though the cuticle were already separated and ready to drop away from the fibers at the slightest dislodgment at the time the loose-core test is made, it remains clinging to the fibers in an undisturbed condition as the core is withdrawn. It is therefore necessary to devise a test in which the cortex is not handled as a single unit and in which the stages of retting in the different parts of the cortex may be observed.

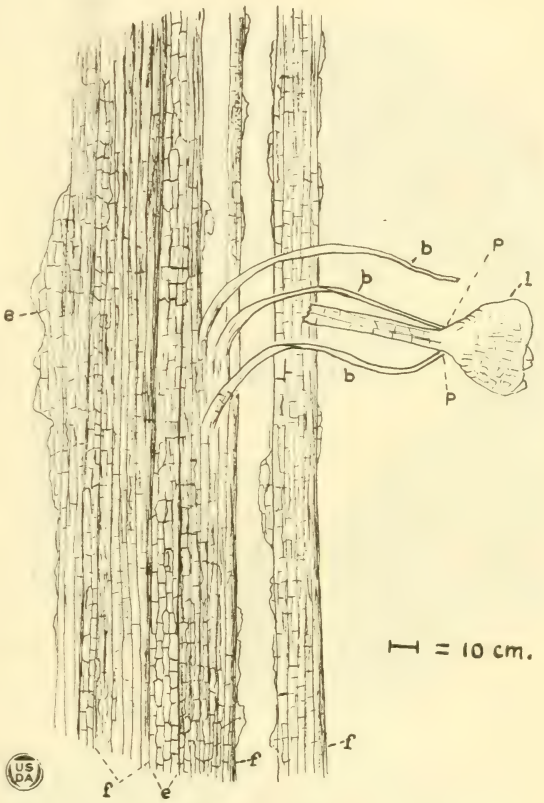

FIG. 12.—Retting flax, showing the persistence of the leaf scars. The process of retting has here reached one of the last stages. The cortex has separated from the wooden core, but is still almost intact. The structure of the epidermis shown as part of the underlying tissue has been destroyed. Explanation: b = Fiber branches, e = epidermis, f = fiber bundles, l = leaf scar, p = point of attachment. Note how the fiber branches cling to the leaf scar at points of attachment.

A difficulty is experienced in testing wet flax stems for completion of retting regardless of the method used; when the stems are withdrawn, one at a time, from the retting tanks which are tightly packed with flax straw, all or part of the cortex may be rubbed off by contact with the adjacent stems. The stem, being in the nature of a wedge, slips out more readily if it is withdrawn from the butt end of the bundle. This precaution is not sufficient to prevent injury to the cortex from contact with the other stems. The diffi-

culty may be entirely overcome, however, through the use of test cylinders placed at intervals in each tank. The test cylinders are packed loosely, so that the stems may be withdrawn one at a time without rubbing against each other. Test cylinders may be made of three thin boards nailed together so as to form a three-sided prism, with a half-inch crack along one edge to permit the free circulation of water and with a small triangular piece of wood nailed across one end for the bottom. Withdrawal of the stems from the test cylinder is facilitated by cutting off the panicles of the stems and placing them in the cylinder with the root ends up. A test cylinder may also be made of a section of bamboo about 2½ inches in diameter by knocking out the nodal partitions in a piece long enough to hold the stems and boring many holes about 1 centimeter in diameter in the side for water circulation.

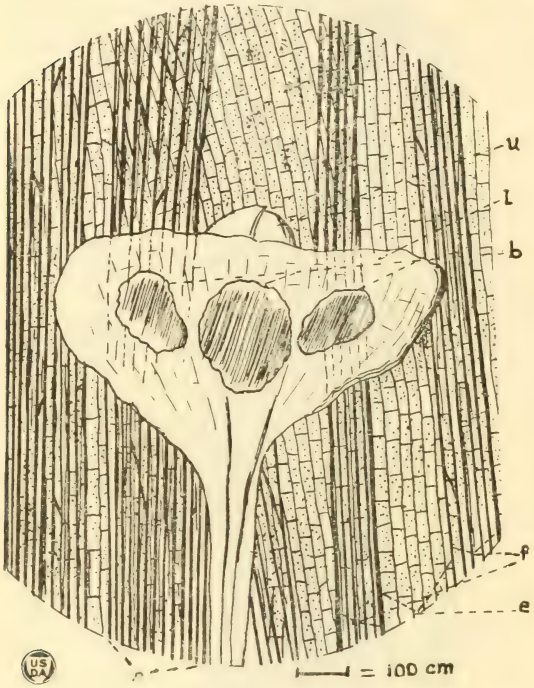

FIG. 13.—Retting flax, showing the persistence of the leaf scars. Retting has disintegrated nearly all the tissues in the cortex except the fiber bundles and the epidermis that overlaps them and holds them together. The leaf scar is partly disintegrated, exposing the bundle traces. Explanation: *b* = Bundle traces, *e* = epidermis, *f* = fiber bundles, *l* = leaf scar, *u* = undeveloped bud.

In the loose-core test the wooden core is moved in the direction of the root end of the stem, and the cortex is held stationary. There are a number of other ways in which the cortex and the wooden core may be separated, and these are divided into three groups. In group 1 are included two ways of making the loose-core test, in which the total resistance to separation of cortex and core may be felt at once. In group 2 are included various ways of testing the dissolution of the leaf scars, and these tests are therefore called leaf-scar tests; in the leaf-scar tests the resistance to separation of cortex and core may be observed at each node, one at a time. In group 3 are included the epidermis tests, in which it is intended to show the fineness of division of the fibers and the extent of the disintegration of the epidermis as indicated by the quantity of cuticle that has separated from the stem. In testing the efficiency of these various methods a double objective may be kept in mind: (1) What test or combination of tests is the most dependable for deciding when to terminate the retting process, and (2) what test is easiest

made by inexperienced hands? In other words: (1) What test which may be confirmed by examination of the fiber in the dry state gives positive indication that retting is complete? (2) what test from the viewpoint of the inexperienced worker gives the strongest indication that retting is complete?

The various ways that have been tried in this study for mechanically separating the cortex from the wooden core are listed as follows:

Group 1.—Loose-core tests: The cortex is held stationary.

(1) The loose core test made toward the root end of the stem.
(2) The loose-core test made toward the panicle end of the stem.

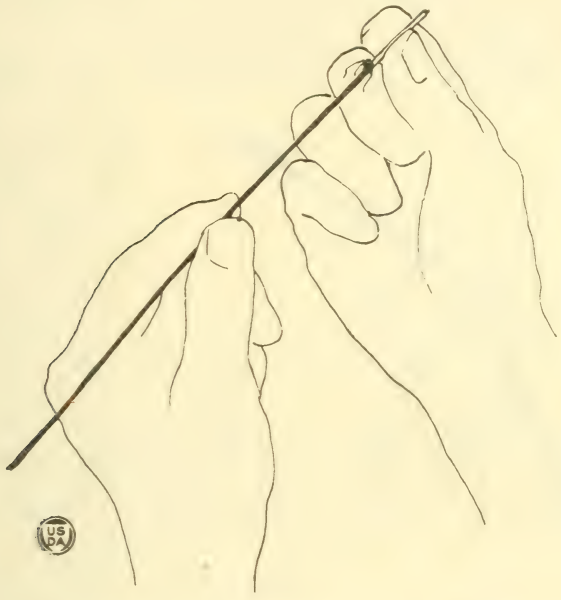

FIG. 14.—Step 1 in the loose-core test of retting flax fibers. The cortex is shoved back from the wooden core so as to leave several centimeters entirely free from fibers.

Group 2.—Leaf-scar tests: The wooden core is held stationary.

(3) The entire girth of cortex is peeled away from the wooden core, beginning at the basal end of the stem and keeping the cortex parallel to the core.
(4) The same as test 3 except that the peeling is started at the panicle end of the stem.
(5) Peeling the cortex from the base end of the stem toward the panicle and keeping it at a 30° to 45° angle to the wooden core.
(6) The same as test 5 except that the peeling is started at the panicle end of the stem.
(7) Pulling the entire cortex away from the wooden core, starting at the base end of the stem and keeping the cortex at right angles to the core.
(8) The same as test 7 except that the test is started at the panicle end of the stem.

As an indication that retting is incomplete, the resistance to separation of the cortex from the wooden core is almost invariably strongest at the nodes. Fiber branches and wood branches cling to the leaf

scars at the nodes long after the cortex is separated from the core along the internodes. Figure 18 shows on the left a loose-core test made toward the root end of a stem in which retting is incomplete, the fibers being gathered in tangled masses at the nodes. On the right is another stem removed during the same stage in retting. In this the cortex has been peeled away from the internodes but the fibers cling to the leaf scars.

The efficiency of tests 1 and 2 of the loose-core group is about the same, although test 1 may be depended upon to offer resistance to separation more nearly up to the end point of retting. Test 2 has another objection in that the projections of wood at the nodes under the leaf scars may catch the fibers and cause them to tangle even after retting is completed.

The tests grouped under the heading "Leaf-scar tests" are characterized by a distinct tugging that may be felt at each node as the entire cortex is peeled away from the wooden core. The entire cortex is used, rather than a strip, as the entire cortex affords additional resistance to separation, which it is necessary to overcome in splitting the cortex on the opposite side of the stem from which it is pulled. The core is held stationary and in a horizontal position while the cortex is pulled vertically. The greatest resistance to separation was found in leaf-scar test 7 (fig. 19), in which the cortex is peeled away at right angles to the core and toward the panicle end of the stem. Test 8 was almost as efficient in this respect as test 7, but had the same objection as the second type of loose-core test, since a confused tangling of fibers may result while making the test even after retting is completed. Tests 3, 4, 5, and 6 can not compare with 7 or 8 in resistance to separation of cortex and core, and their relatively low resistance to separation is lost some time previous to the completion of retting. Figure 20 shows the beginning and the end of a leaf-scar test made parallel to the stem. Note how the fibers cling to the leaf scars.

FIG. 15.—Step 2 in the loose-core test of retting flax fibers. The wooden core is broken 6 to 9 inches above the first break where the cortex has been shoved back

Of these eight numbered tests, the most efficient members of the loose-core and leaf-scar groups remain to be compared. These are test 1, in which the loose-core test is made by pulling the wooden

core out toward the root end of the stem, and test 7, in which the leaf-scar test is made by peeling the girth of cortex away from the wooden core at right angles and toward the panicle end of the stem. For best results with test 7 the hand holding the stem is moved along directly behind the place where the peeling takes place, and the stem is held horizontally. These two tests are hereafter designated, respectively, as the loose-core and the leaf-scar tests proper. They were compared with considerable accuracy, as the same stems were used

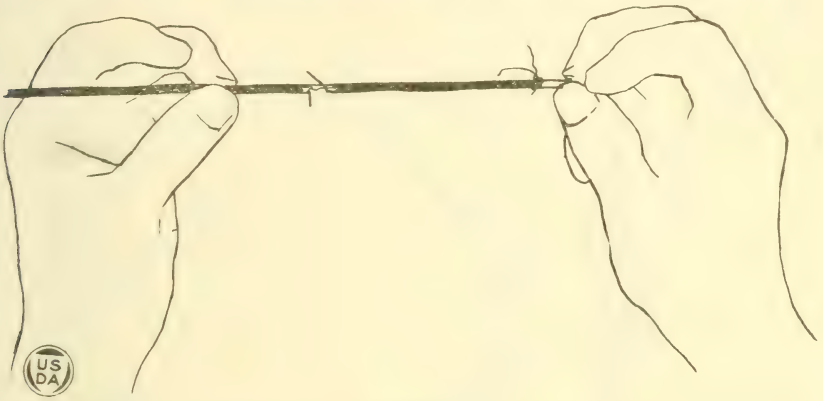

FIG. 16.—Step 3 in the loose-core test of retting flax fibers. One hand holds the stem above the second break in the wooden core, while the other exerts a pull on the exposed lower end.

in making both tests. At each interval when observations were made 10 stems were withdrawn one at a time and the tests alternated, using the root-end half of the first stem for the loose-core test and the panicle-end half for the leaf-scar test and then reversing the two

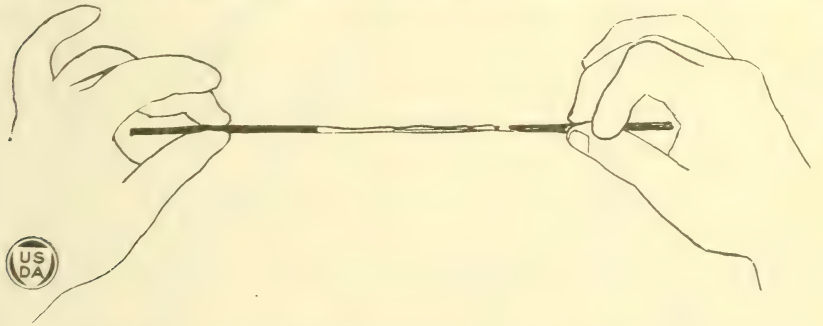

FIG. 17.—Step 4 in the loose-core test of retting flax fibers. Retting is said to be complete if the wooden core slips easily out from the cortex without any of the fibers clinging to it.

portions used for the next stem. In this way 10 tests were made with each method of testing and in each case 5 root-end and 5 panicle-end halves were used from the same 10 stems. The resistance to separation was lost with the loose-core test long before the completion of retting, but the resistance to separation was retained in the leaf-scar test until retting was practically completed. At the time when the loose-core test gave positive indication that retting was completed, through the loss of resistance to separation of the cortex and

wooden core, the cortex was only partly retted, and the fibers were not sufficiently separated. Hundreds of tests have been made during all stages of retting, and without question the resistance to separation offered in the leaf-scar test is more dependable than the loose-core test as an indication that retting is not completed. If there is the slightest tendency for the fibers to cling at the nodes the leaf-scar test will register a tug at each leaf scar.

Closely associated with the loss of resistance to separation in the leaf-scar test are several changes in the flax stem. Just previous to

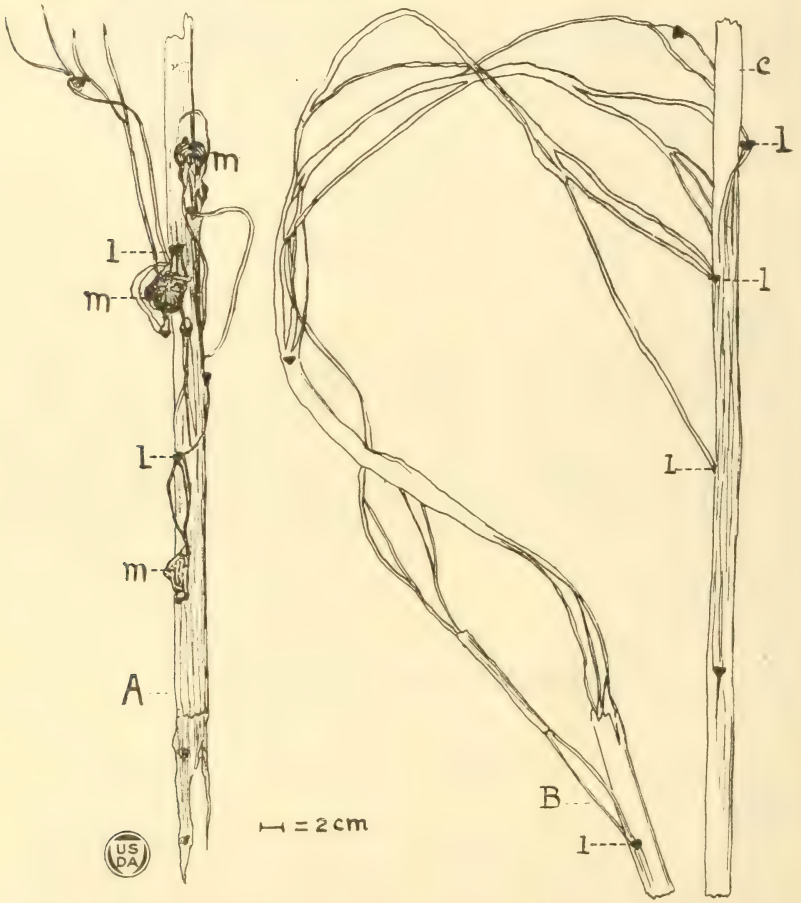

FIG. 18.—Loose-core test in partly retted flax stems: *A*, Loose-core test, showing how fibers and epidermis slough off and gather in tangled masses (*m*) that cling to the leaf scars (*l*). *B*, Stem removed from the retting solution and fibers peeled gently away from the wooden core (*c*). Note how the fibers cling to the leaf scars (*l*), and compare this with Figure 12.

the positive leaf-scar test a slight swelling at the nodes may be observed, and the leaf scars have so nearly disappeared throug gradual disintegration that it is difficult to observe more than a tiny spot at the center of each leaf scar, a spot that is only slightly darker in color than the rest of the stem. If the few stems to be tested are

plunged into a glass cylinder of clear warm water, the external appearance may be observed readily. The stems should not be placed in water that is colder than the retting water if they are intended for use in testing for completion of retting, as the fibers cling more tenaciously to the stems when cold. Almost simultaneous with the positive leaf-scar test the cuticle will be noticed floating away from the stems in pieces 3 to 5 centimeters long and several millimeters wide, and at any place where there happens to be a crooked bend in the flax stem the individual fiber bundles are to be seen drawn away from the wooden core. Also at this time the stems become light yellow to almost white in color, and the cloudy or murky appearance present at an earlier stage has been lost. The disappearance of the leaf scars, a slight swelling at the nodes around the leaf scars, a tendency of the fibers to pull away from the core, a lightening of

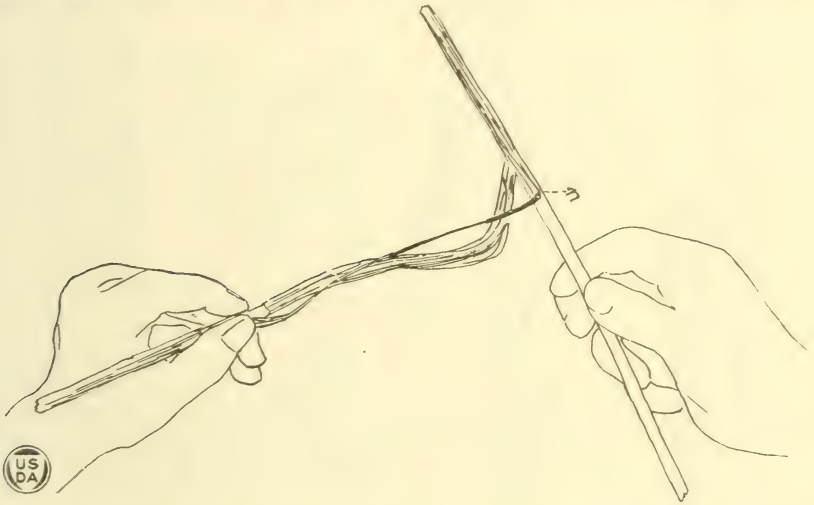

FIG. 19.—Leaf-scar test for the completion of the retting process of flax fibers. Retting is incomplete. Note the fibers clinging at the leaf scar or node (*n*). The sizes of the flax stems in Figures 19 and 21 to 23 are exaggerated as compared with the size of the hands.

the stem color, and the mechanical separation of the cuticle all appear to be associated with the positive leaf-scar test.

Retting experiments have been conducted to determine whether the best quality of fiber may be obtained through the use of the leaf-scar test or whether the process should be carried still farther and the epidermis test used to supplement the leaf-scar test. The epidermis test is made by breaking the wooden core and moving one portion of the stem about 3 inches to one side of the other portion, keeping at the same time the axes of the two portions parallel, and then swishing the cortex to and fro in clear water. If all the cuticle separates and floats away in pieces, showing that the epidermis is entirely destroyed, leaving the fibers of fine diameter and well separated from the rest of the cortex, retting is complete. If, as in Figure 21, the first step in the epidermis test shows the epidermis clinging in practically an undivided condition to the fibers, retting is incomplete. Figure 22 shows the first step in the epidermis test when the fibers are so well separated and retting is so nearly complete that it is necessary to carry the test still farther and swish

through water in order to reach a decision. Figure 23 shows an epidermis test after the fibers have been swished through water. The fibers here are well separated, and the pieces of cuticle have separated from the fibers at all points except at the leaf scars where the waterproof unions formed by the suberin between the fibers and the epidermis are not entirely disintegrated. Retting is almost complete when this stage is reached, and the process should be watched closely. It is possible that these remnants of the epidermis could be removed by breaking and scutching.

FIG. 20.—Leaf-scar test in partly retted flax, made toward the root end of the stem and parallel to the wooden core. On the right is the beginning of the test and on the left the end of the test. Retting is incomplete. Note how the fibers cling to the leaf scars where the cortex has been peeled away from the core in the left-hand figure.

Sellergren states that traces of pectin and parenchyma cells are not entirely removed during the process of retting and that the removal of these impurities during the processes of breaking, scutching, and combing gives the fiber increased luster.[11] Retting should be carried on, however, up to the very last stage and until serious weakening of the fiber would result if continued. The cleaner the retting process leaves the fiber the less will be the necessity of scutching to remove the nonfibrous portions and consequently the less will be the wastage of fiber resulting from the impacts of the scutching blades.

Good samples of fiber have been obtained through the use of the leaf-scar test. In some of these samples the fiber was so well separated from the wooden core that no scutching was necessary, and it could be hand hackled directly after running it through the brake. The use of the loose-core test in our experimental work, has been discontinued, being replaced by the leaf-scar and epidermis tests combined. The retting process has been carried on as far as a positive epidermis test without any apparent loss in fiber strength. It is be-

[11] Sellergren, Gustav. Inhemska fiberväxter. *In* K. Landtbr. Akad. Handl. och Tidskr., arg. 60, p. 388–424, 13 fig. 1921. (Manuscript translation by Ebba Oleson Campbell, p. 10. On file in the Office of Fiber Investigations, Bureau of Plant Industry.)

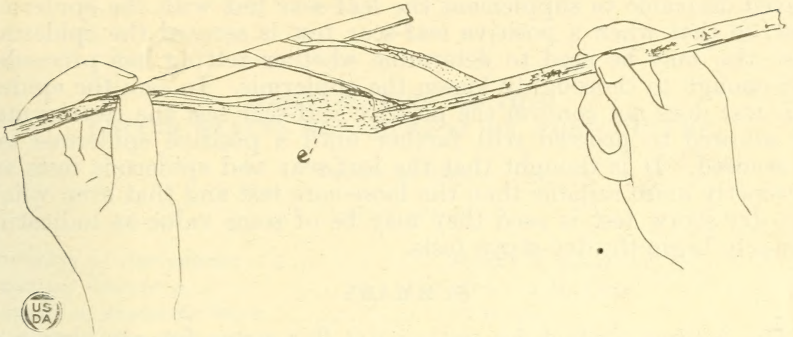

FIG. 21.—Epidermis test in incompletely retted flax. The epidermis (*e*) is clinging to both nodes and internodes in large pieces, showing that the retting process is not complete.

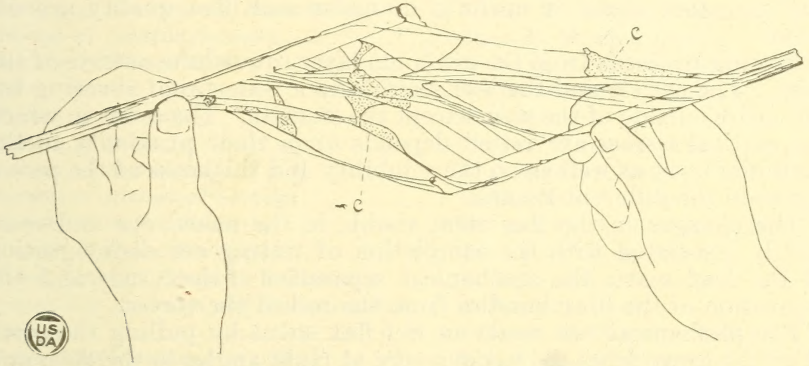

FIG. 22.—Epidermis test of flax fibers when retting is nearly complete. The fibers are well separated and of fine diameter. Pieces of cuticle (*c*) are clinging in spots. When this stage of retting is reached it is necessary to swish the fibers to and fro in water in order to tell whether the epidermis is well loosened.

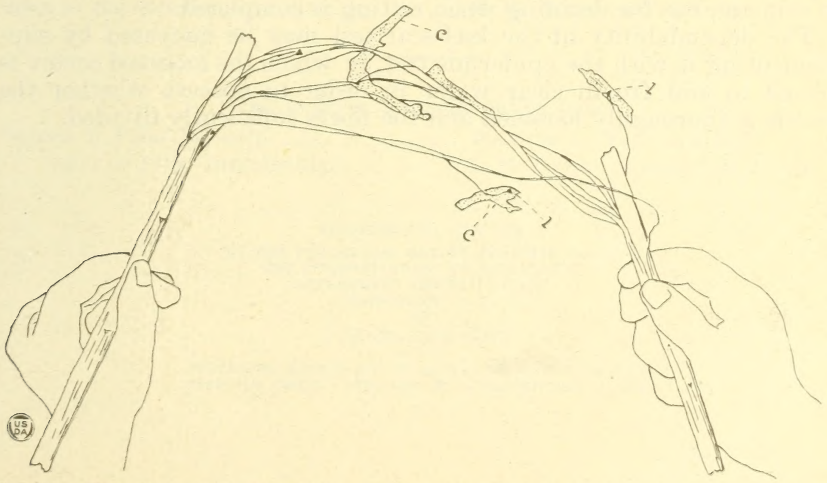

FIG. 23.—Flax fibers at the completion of the epidermis test. Retting is at the same stage as that shown in Figure 22. The cortex is shown after it has been swished to and fro in water. Retting is almost complete, and the cuticle (*c*) is separated except at the leaf scars (*l*).

lieved desirable to supplement the leaf-scar test with the epidermis test, so that when a positive leaf-scar test is secured the epidermis test also may be used to determine whether retting has proceeded far enough to thoroughly loosen the epidermis. In case the epidermis test does not confirm the positive leaf-scar test the retting may be allowed to proceed still farther until a positive epidermis test is secured. It is thought that the leaf-scar and epidermis tests are distinctly more reliable than the loose-core test and that even where the dry-straw test is used they may be of some value as indicating when to begin the dry-straw tests.

SUMMARY.

The present method for testing wet flax stems for completion of retting is not dependable.

Variations in straw quality may interfere with securing a good ret, and therefore stems of uniform diameter and fiber quality are desired.

Retting proceeds from the cambium layer toward the outside of the stem. The cuticle and the leaf scars form a waterproof covering for the entire outside of the stem except the stomata. The order in which the cortical tissues are retted depends upon their proximity to the cambium layer as well as on the solubility and thickness of the pectin layers in the different tissues.

The changes in the flax stem visible to the naked eye and most closely associated with the completion of retting are disintegration of the leaf scars, the mechanical separation of the cuticle, and the separation of the fiber bundles from the rest of the cortex.

The mechanical test made on wet flax stems by pulling the girth of cortex away from the wooden core at right angles to the stem and starting near the root end is easily made by inexperienced workers, because the resistance to separation at the nodes is marked. This type of leaf-scar test is more dependable than the loose-core test now in common use for deciding when retting is completed.

The dependability of the leaf-scar test may be increased by supplementing it with the epidermis test, in which the loosened cortex is moved to and fro in clear water in order to observe whether the cuticle is thoroughly loosened and the fibers sufficiently divided.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE.

October 15, 1923.

Secretary of Agriculture	HENRY C. WALLACE.
Assistant Secretary	HOWARD M. GORE.
Director of Scientific Work	E. D. BALL.
Director of Regulatory Work	WALTER G. CAMPBELL.
Director of Extension Work	C. W. WARBURTON.
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Agricultural Economics	HENRY C. TAYLOR, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	W. B. GREELEY, *Chief.*
Bureau of Chemistry	C. A. BROWNE, *Chief.*
Bureau of Soils	MILTON WHITNEY, *Chief.*
Bureau of Entomology	L. O. HOWARD, *Chief.*
Bureau of Biological Survey	E. W. NELSON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Fixed Nitrogen Research Laboratory	F. G. COTTRELL, *Director.*
Division of Accounts and Disbursements	A. ZAPPONE, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*
Federal Horticultural Board	C. L. MARLATT, *Chairman.*
Insecticide and Fungicide Board	J. K. HAYWOOD, *Chairman.*
Packers and Stockyards Administration *Grain Future Trading Act Administration*	CHESTER MORRILL, *Assistant to the Secretary.*
Office of the Solicitor	R. W. WILLIAMS, *Solicitor.*

This bulletin is a contribution from

Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Office of Fiber Investigations	L. H. DEWEY, *Botanist in Charge.*

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
5 CENTS PER COPY

PURCHASER AGREES NOT TO RESELL OR DISTRIBUTE THIS COPY FOR PROFIT.—PUB. RES. 57, APPROVED MAY 11, 1922

▽